# Performance evaluation of the ADMS-Urban model in predicting $PM_{10}$ concentrations at the roadside in Chennai, India and Newcastle, UK

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## Abstract

Recent economic development in many Asian and European countries has shown an increase in vehicle kilometre travel (VKT) in many cities, which has resulted in an increase in the vehicular pollution levels. In particular, particulate matter (PM) concentrations emitted from vehicles are at alarming levels in most of the cities of the world. Therefore, there is growing interest in the formulation of local level air quality management system to tackle vehicular emissions. Many mathematical models have been widely used as tools in urban air quality management. In the present paper, an attempt has been made to evaluate the performance of the ADMS Urban model in predicting roadside PM concentrations at two cities namely Chennai, India and Newcastle, UK during critical winter period of the year 2009. The statistical parameters such as Index of Agreement (IA), Fractional Bias (FB), Normalized Mean Square Error (NMSE), Geometric Mean Bias (MG) and Geometric Mean Variance (VG) have been used to evaluate the ADMS model performance. Results indicated that the roadside PM concentrations predicted by the ADMS model are reasonably accurate for Newcastle than at the roadside in Chennai.
*Keywords: air quality, particulate matter, model, management, statistical indicator, meteorology.*

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# 1 Introduction

Air pollution from motor vehicles is one of the most serious and rapidly growing environmental problems in the large cities of the developing world. In many cases, the monitored pollutant concentrations exceed the world health organization (WHO) air quality guidelines or national ambient air quality standards (NAAQS) set in their countries. The recent trends of air pollution in India and UK are showing a low level in most of the criteria pollutants except particulate matter (PM) and oxides of nitrogen concentrations in both the cities. In the United Kingdom, about 80% of the road emissions are generated from particulate matter of which road transport is the dominant share [1]. Vehicular exhaust derived pollution and its effect on human health is now becoming a matter of concern in many urban areas. According to recent epidemiological and toxicological studies, the high concentrations of airborne particles are associated with significant impacts on human health [2]. This holds especially for the fine and ultrafine particle size ranges due to their ability to penetrate deep into the human body. A study conducted by Srimuruganandam and Nagendra [3] showed that the 24-hour average PM10 and PM2.5 concentration are violating of NAAQS as well as world health organisation standards (WHO) during winter and monsoon season and minimus in summer season. Source apportionment studies of Chennai have also revealed the exceedances of particulate matter concentrations above NAAQS in residential areas [4]. Therefore, it becomes necessary for the authorities to assess the quality of air and implement control policies and strategies.

In the recent past, many cities have been developed air quality management (AQM) strategies to achieve a specified set of ambient air quality standards (AAQS) or rules. Air quality models plays an important role in formulating air pollution control and management strategies by providing guidelines for better and more efficient air quality planning. Air Quality Models represent essential computational tools for predicting the air quality impacts of emissions from road traffic and also help in testing the accuracy of monitoring equipments once it is validated. In the present work, dispersion models namely ADMS-Urban has been used to simulate the air quality at selected locations in Chennai and Newcastle cities. Further, model sensitivity with respect to traffic and meteorological characteristics has also been studied.

# 2 Methodology

## 2.1 Study region

Figure 1 shows the details of study region in Chennai city, India. The study area is located in the premises of Indian Institute of Technology Madras (IITM), Sardar Patel Road, Chennai city in India. Traffic flows on SP road is about 0.17 million vehicles per day. Braking is frequent on SP road due to the presence of two busy traffic intersections within a distance of 700 meters. The terrain of the study region is considered as plain and flat terrain (terrain height is 7.6 m from


Figure 1: Description of study area in Chennai, India.

mean sea level). At this site, there is no local stationary source emission except emissions from road traffic. The PM monitoring instrument was kept at 1.2 m height from ground level and 7 m away from the centerline of SP Road.

The project site in Newcastle city is located at $54^0$ 58' 40 N and $1^0$ 36' 49" (Figure 2) which is also one the busiest intersection of Newcastle upon Tyne. This intersection comes under air quality control regions (AQCRs). The whole intersection has been divided into three different roads. The monitoring site is situated near to road i.e. 20 m at city centre. The city centre monitoring station works under urban centre air quality station which is operated under Automatic Urban and Rural Network (AURN), the main air quality compliance network for DEFRA. The monitored data of both cities are used for validation of the model.

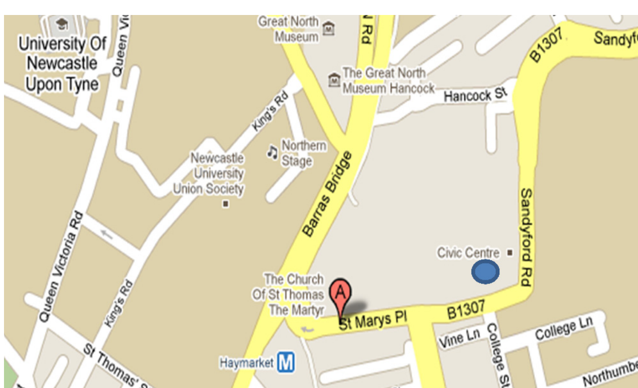


Figure 2: Description of study area in Newcastle city, UK.

## 2.2 Traffic characteristics

The traffic volume count (TVC) has been monitored continuously for a week at a Sardar Patel road using automatic traffic flow recorder (Video). The traffic flow for Newcastle city has been obtained from SCOOT profile. The traffic flow at Chennai intersection is about 1,70,000 and that in the intersection at Newcastle city is about 25000. The morning peak flow occurs between 8am and 10am and afternoon peak occurs between 5pm and 7pm (Figure 3). The fleet composition in Chennai is dominated by two-wheelers (about 51%) followed by cars (34%)

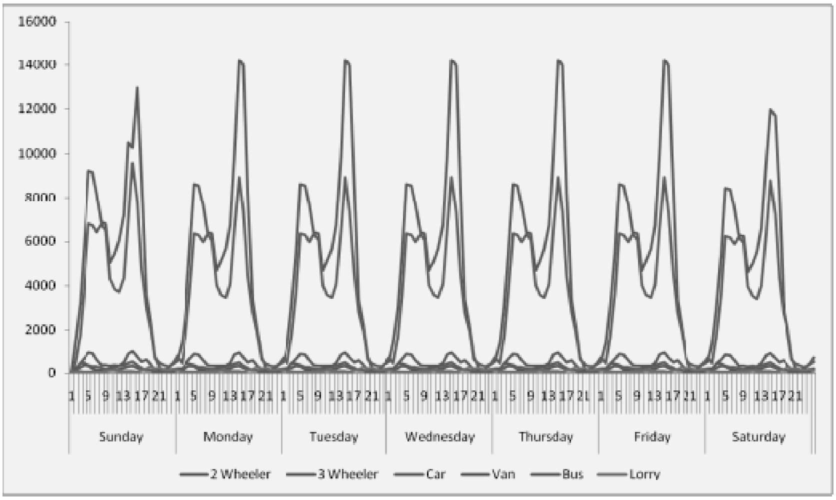


Figure 3: Traffic flow on SP road in Chennai city.

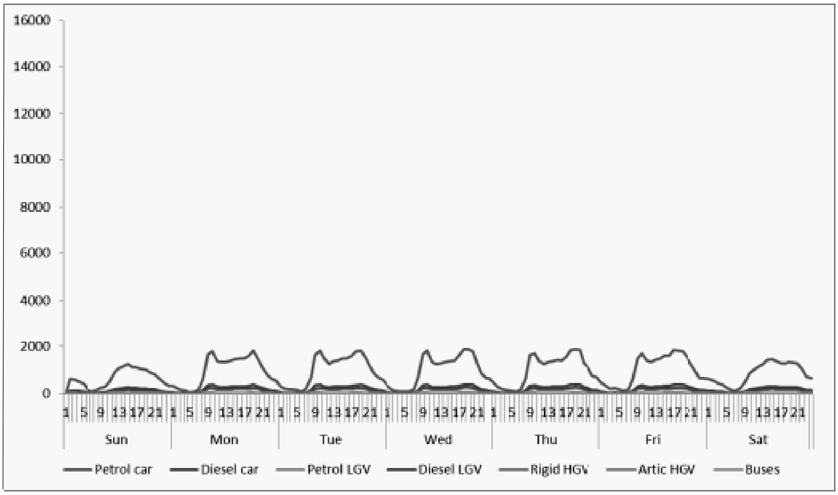


Figure 4: Traffic flow Newcastle city centre road in Newcastle city.

and three-wheelers (6%), respectively. Bus, lorry and van contribute a small percentage on SP road. The traffic pattern in Newcastle is somewhat uniform over weekdays and minimum in weekends as compared to weekdays. The diurnal traffic flow shows that morning peak flow occurs between 7 am and 11 am and evening peak occurs between 5pm and 8pm (Figure 4). The fleet composition of Newcastle is dominated by petrol car about 60% followed by diesel car (30%). HGV, LGV and buses contribute a small percentage.

### 2.3 PM Emissions

PM emission has been estimated using the methodology suggested by Righi et al. [5]. ARAI [6] emission factors for Indian vehicles are used for Chennai site and DfT 2009 is used for Newcastle site [1]. The UK emission factors are speed depended unlike Indian vehicles emission factors. Traffic monitoring data for year 2004 was used to calculate emission rate for the year 2009 (extrapolation) on the basis of business as usual.

### 2.4 Meteorological data

The main input meteorological parameters for ADMS model are wind speed and wind direction plus one of the following parameters, cloud cover, heat flux or reciprocal of Monin-Obukhnov length. The parameter solar radiation will be used only if NOx chemistry has to be used [7]. Sequential hourly meteorological data for the winter period (December 2008-February 2009) were obtained from Laga Systems, Hyderabad. The wind rose for the three months of both the cities is shown in Figures 5 and 6.

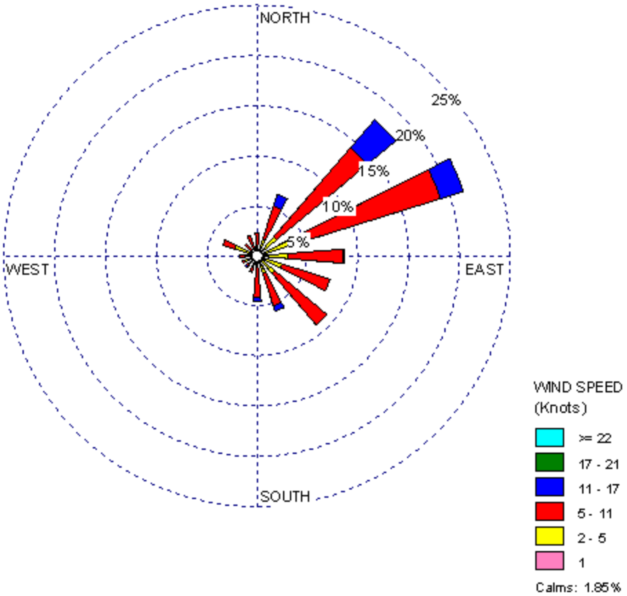


Figure 5: Windrose for Chennai.

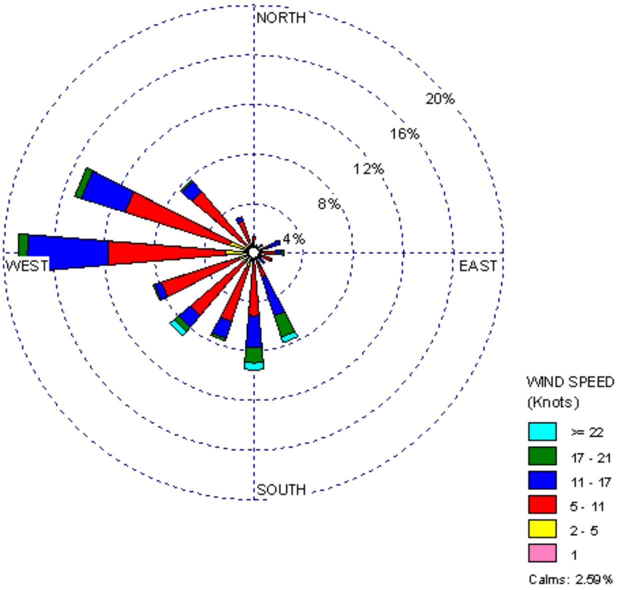


Figure 6: Windrose for Newcastle.

The windrose diagrams revealed that about 2.5% of winds are calm in nature (<1 m/s) and an average wind speed of 4.64 m/s for Chennai city and 4.82 m/s for Newcastle city. For Newcastle city, the predominant wind direction is towards west direction and for Chennai city, it is North-West. Table 1 summarizes the meteorological characteristics at both cities.

Table 1: Summary of meteorological characteristics at Chennai and Newcastle cities.

| | Wind Speed (m/s) | Cloud Cover (tenths) | Temperature (degree Celsius) | Relative Humidity (percentage) | Pressure (millibars) |
|---|---|---|---|---|---|
| Chennai | | | | | |
| Maximum | 7.8 | 10.0 | 28.9 | 100.0 | 1016.0 |
| Minimum | 0.0 | 2.0 | 19.4 | 49.0 | 1004.0 |
| Average | 3.66 | 3.0 | 25.19 | 76.4 | 1009.79 |
| Standard Deviation | 1.62 | 2.0 | 1.38 | 8.15 | 1.86 |
| Newcastle | | | | | |
| Maximum | 14.0 | 10.0 | 10.3 | 100.0 | 1030.0 |
| Minimum | 0.0 | 2.0 | -4.8 | 58.0 | 960.0 |
| Average | 4.82 | 4.0 | 3.17 | 91.63 | 1000.47 |
| Standard Deviation | 2.37 | 2.0 | 3.29 | 7.55 | 15.75 |

### 2.5 PM10 sampling

The PM is measured at SP road using a real-time GRIMM portable dust monitors with the model number 107 (Grimm Technologies, Inc.). The model 107 measures the particle mass concentrations in terms of $PM_{10}$, $PM_{2.5}$ and $PM_1$ with a resolution of 1 µg/m$^3$. The instruments use a light-scattering technology for single-particle counts. The flow rate of instrument is 1.2 L/min. The 47-µm poly-tetra-fluoro-ethylene (PTFE) filters with 0.2 µm size are used for collecting the dust samples. The measurement of PM mass concentrations has been made from October to December 2009. The 1 minute averaged values of both PM mass and numbers have been later converted into one hour average values.

At Civic centre in Newcastle city, PM concentrations are monitored using high volume sampler installed at Civic Centre, Newcastle. The observed daily concentration values under changing traffic and environmental conditions have been used for evaluation of ADMS model performance. The model performance was carried out for critical winter period (December 2008-February 2009).

### 2.6 Description of ADMS Urban model

ADMS – Urban (Atmospheric Dispersion Modeling System) has been developed by Cambridge Environment Research Consultants, United Kingdom. It is an advanced model for calculating concentrations of pollutants emitted both continuously from point, line, volume and area sources, and discretely from point sources. In ADMS-Urban road model sources are treated as line sources. Each road source is decomposed into a maximum of 10 source elements and the concentration of each element is approximated by a crosswind line source of finite length (CERC [7]). The model includes algorithms which take account of the following: effects of main site building, complex terrain, wet deposition, gravitational settling and dry deposition, short term fluctuations in concentration, chemical reactions, radioactive decay and dose plume rise as a function of distance, jets and directional releases, averaging time ranging from very short to annual; condensed plume visibility meteorological preprocessor.

### 2.7 Statistics for model performance evaluation

The statistical descriptors Index of Agreement (IA), Fractional Bias (FB), Normalized Root Mean Square Error (NRMSE), Geometric Mean Bias (MG) and Geometric Mean Variance (VG) have been used to evaluate the performance of ADMS model.

$$\mathrm{IA} = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \qquad (1)$$

$$\mathrm{FB} = 2(P_i' \text{-} O_i) / (P_i' + O_i') \qquad (2)$$

$$\text{NMSE} = \frac{\sqrt{\sum_{i=1}^{n}(Pi-Oi)^2}}{n} \tag{3}$$

$$\text{MG}= \exp(\ln Oi - \ln Pi) \tag{4}$$

$$\text{VG}= \exp(\ln Oi - \ln Pi)^2 \tag{5}$$

In the above equations, $O_i$ is the observed value; $P_i$ is the predicted value by ADMS and $\bar{O}$ is the average of observed values. IA indicates how much the predicted value departs from observed values. It has a theoretical value between 0 and 1, latter indicates perfect agreement. NRMSE is an estimator of the overall deviations between the observed and predicted values. Smaller values of NRMSE indicate better performance and are not biased towards model that over predicts or under predict. FB, a dimensionless number, represents the relative difference between observed and modeled values in a bounded range [7]. The value of FB lies between -2 and +2. MG and VG are measures of dispersion which finds application when values in a set follow a log normal distribution. A perfect model will have both MG and VG equal to 1.0 [8]. However, a model will be deemed acceptable if: NRMSE≤0.5; -0.5≤FB≤0.5; 0.75≤MG≤1.25; 1≤VG≤1.25 [9].

# 3 Results and discussions

## 3.1 PM10 mass concentration trend

The monitored $PM_{10}$ concentrations for the study period (December 2008 to February 2009) at Chennai and Newcastle City Centre road are shown in the Figure 7. The 24-hr average pollutant levels for the three months are 130.39 µg/m$^3$ for Chennai city and 16.38 µg/m$^3$ for Newcastle. High PM concentrations are found during calm conditions prevail. Similarly the concentrations are found to be high when the wind is towards the receptor location. The $PM_{10}$ mass concentration at the SP road is found to be higher than the specified NAAQS limit for the residential area (100 µg/m$^3$). In Figure 7, a clear diurnal and weekly cycles were observed at Chennai study site. In diurnal cycles two peaks were observed corresponding to morning and evening peak traffic flow. The maximum PM concentration was observed between 8AM to 10AM in the morning and in the evening between 5PM to 10PM. The low PM values observed during night time between 11PM to 6AM beacause of lean traffic flow. During afternoon between 12 noon to 3PM the PM concentation is found to be in the lower range.

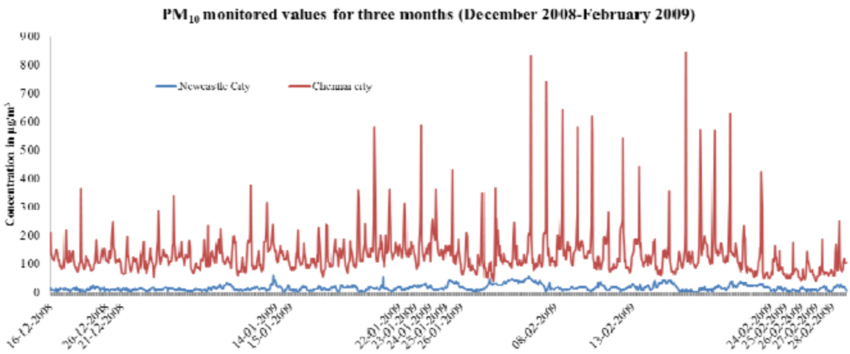


Figure 7: Variation in monitored $PM_{10}$ concentrations at Chennai and Newcastle city.

### 3.2 Performance evaluation of ADMS model

Table 2 presents the statistics of ADMS model performance during critical winter period. It is observed that ADMS model predictions are close to observed PM concentrations at Newcastle city. The negative MG values indicate that ADMS model is under predicting the PM concentration at both the site. The IA values of 0.39 and 0.48 indicate that 39% and 48% of the model predictions are error free at Chennai and Newcastle sites, respectively. This is evident from the predicted average and the maximum PM values which are significantly below the observed values. NRMSE values for both sites shows less correlation between observed and predicted values.

Table 2: Summary of ADMS model performance at Chennai and Newcastle city.

| Study site | $PM_{10}$ | IA | FB | MG | VG | NRMSE | Average (µg/m$^3$) | Maximum (µg/m$^3$) |
|---|---|---|---|---|---|---|---|---|
| Chennai | Predicted | 0.39 | -1.03 | 1.36 | 1.04 | 0.19 | 41.33 | 120.11 |
| | Observed | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 | 130.39 | 343.16 |
| Newcastle | Predicted | 0.48 | -1.29 | 1.27 | 1.14 | 0.09 | 4.44 | 28.10 |
| | Observed | 1.00 | 0.00 | 1.00 | 1.00 | 0.00 | 16.38 | 59.00 |

## 4 Conclusion

Mathematical models have been widely used as a tool in urban air quality management in developed countries. The ADMS model is being widely used in Europe for air quality assessment. However, its application is limited in developing countries such as India due to lack of readily available input data to the test model and time and cost involved in collecting the required data. In the present paper, the performance of Gaussian based dispersion model namely ADMS-Urban in predicting vehicular air pollutant (PM) concentration at road sides in Chennai city and Newcastle city has been evaluated. The model performance is evaluated using statistical parameters such as Index of Agreement (IA), Fractional Bias (FB), Normalized Root Mean Square Error (NRMSE), Geometric Mean Bias (MG) and Geometric Mean Variance (VG). Results indicated that ADMS model is able to predict the PM concentrations with reasonable accuracy. The IA for ADMS is found to be 0.39 for Chennai city and 0.48 for Newcastle city.

## Acknowledgements

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